UPPER WIND FORECASTING

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[Boeing School of Aeronautics, Oakland, Calif., June 1937]

INTRODUCTION

The problem of determining the direction and velocity of the wind in the upper levels of the atmosphere is becoming increasingly important with the development of long-range flying equipment. In long flights the upper wind distribution is one of the prime considerations in determining the balance between pay load and fuel. Companies operating over distances of 1,500 miles or more use the upper wind data to estimate the amount of gasoline to be carried. An increase in the number of airway traffic control stations also makes necessary accurate upper wind information for estimations of flight time from station to station.

The problem then is to select a satisfactory method of representing the upper wind field so that the meteorologist may visualize the changes which might occur and to estimate these changes as accurately as possible.

In the United States upper wind observations are made mostly by single theodolite observations of free balloons. This method of observation assumes a constant rate of ascent of the balloon and the velocity is given by taking the resultant of the horizontal components of the average velocities for each two successive 600-foot levels. The meteorologist at present smooths his surface pressure map which is made up of very exact readings of mercurial barometers. The smoothing process damps out small local variations and should be used on weather maps representing any meteorological element. The most natural method seems to be to draw stream lines of the air flow.

COMPUTATION OF A GEOSTROPHIC WIND SCALE

Since the magnitude of wind velocity is proportional to the pressure gradient, a scale may be constructed which will give the correct spacing of the stream lines and the upper wind maps will be comparable to the surface pressure maps; the actual value of the pressure is immaterial. The pressure gradient, however, depends upon two components, the geostrophic component and the cyclostrophic component. This is shown in the following equation: [1]

$$\frac{1}{D}\frac{dP}{dN}=2\omega V\sin L\pm\frac{V^2}{r}$$

where D is the density of the air, $\frac{dP}{dN}$ the pressure gradient, ω the angular velocity of the earth, V the wind velocity, L the latitude, and r the radius of curvature of the trajectory.

The geostrophic component $2\omega V \sin L$ depends upon the latitude and the cyclostrophic component $\frac{V^2}{r}$ upon the radius of curvature of the trajectory. In the upper wind systems over the United States, especially above 5,000 feet, the cyclostrophic component becomes small in comparison to the geostrophic component.

Neglecting the term $\frac{V^2}{r}$ the equation becomes:

$$\frac{1}{D}\frac{dP}{dN}=2\omega V\sin L$$

[1] D. Brunt, Physical and Dynamical Meteorology, p. 183.

Assuming an average latitude of 40° N. and writing $\frac{dP}{dN}$ as the change of pressure of 0.10 inches of Hg per "x" miles the equation will reduce to:

$$x=\frac{314.57}{DV}$$

where x is the distance between 0.10 in. of Hg isobars or stream lines, D is the air density at any given level in pounds per cubic foot as computed for the standard atmosphere, and V the wind velocity in miles per hour.

Table 1 gives the results of computations for six levels: sea level, 5,000 feet, 8,000 feet, 10,000 feet, 12,000 feet, and 14,000 feet. These may be laid out along the sides of a hexagon on a scale corresponding to that of the map

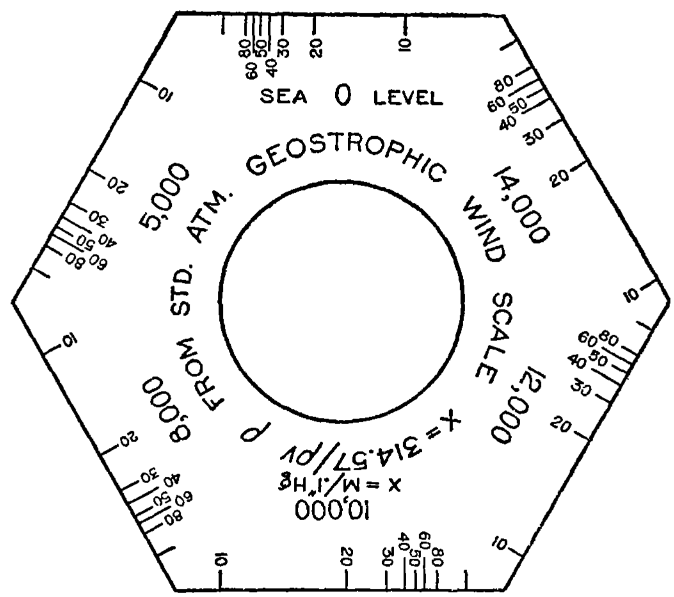

FIGURE 1.—Geostrophic wind scale.

which is being used. Figure 1 shows a scale which was constructed for use on the upper wind charts used by the Weather Bureau.

TABLE 1.—*Geostrophic wind values*

[Distances in miles between 0.10 in. Hg isobars for various wind velocities at different levels]

Level, feet above sea level	Air density, lbs./cu. ft.[1]	Wind velocity in miles per hour						
		10	20	30	40	50	60	80
0	0.0765	411	206	137	103	82	69	51
5,000	.0659	477	239	159	119	96	80	59
8,000	.0601	523	262	175	131	105	87	65
10,000	.0565	557	278	186	139	111	93	70
12,000	.0530	594	297	198	148	118	99	74
14,000	.0497	633	317	211	159	127	106	80

[1] W. R. Gregg, Aeronautical Meteorology, p. 78.

For standard atmosphere at 40° N. latitude, sea level pressure=29.921 in. Hg., temperature=59° F., temperature lapse rate=3.566° F. per 1,000 feet.

CONSTRUCTION OF AN UPPER WIND CHART

Returning now to the problem of determining the structure of the upper wind systems, the problem of forecasting any meteorological element depends mainly on a correct analysis of the latest synoptic condition and a thorough understanding of the history of its development. The actual forecast is merely an extrapolation tempered by physical and meteorological considerations.

The geostrophic wind scale gives a quick method for constructing an upper wind map which will have a physical

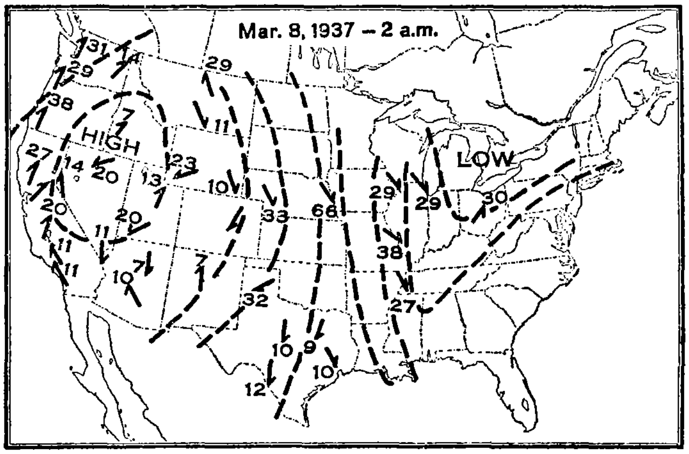

FIGURE 2.—Upper wind map for the 8,000-feet level, 2 a. m. Pacific standard time March 8, 1937.

meaning. With the aid of several consecutive wind charts, say at 12-hour intervals for the desired levels, the meteorologist can see the historical development and obtain a picture which will enable him to visualize the changes which are taking place.

The procedure followed in the construction of an upper wind chart is:

1. Sketch in lightly the approximate streamlines (lines tangent to the instantaneous velocity arrows on the

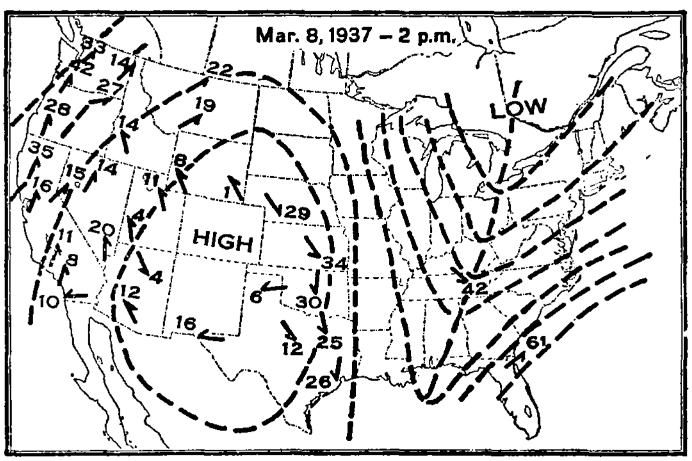

FIGURE 3.—Upper wind map for the 8,000-feet level, 2 p. m. Pacific standard time, March 8, 1937.

wind chart). In some cases the arrow will deviate from the majority of the arrows and the smoothing process is to make an estimate of the average direction of flow. (Only maps for levels 2,000 feet above the surface of the earth or higher should be drawn with streamlines.)

2. The second step is to pick out one streamline which seems to follow smoothly through the field with uniform or uniformly increasing or decreasing wind velocities. This line will be a base from which the rest of the field may be constructed.

3. Neglecting all of the original streamlines except the one chosen as a base, the rest of the field may be constructed by using the average wind velocities in the given area together with the geostrophic wind scale to determine the distance at which the next streamline will be placed. Working from each successive streamline in this manner, a wind field which is similar in appearance to a pressure field will finally be obtained.

Since the streamlines are at distances which are proportional to 0.10 in. of Hg pressure, one can refer to the streamlines as isobars and call the anticyclonic circulations high pressure areas, and the cyclonic circulations low pressure areas.

Figures 2, 3, and 4 show three such fields on three successive upper wind charts for the 8,000-foot level. Figure 2 shows a large anticyclonic circulation over the Great Basin. Figure 3, 12 hours later, shows that the center has moved into New Mexico, and figure 4 shows the same center over Texas.

FORECASTING PROCEDURE

The trajectory of the center is noted from map to map and an extrapolation is made for any given time in the

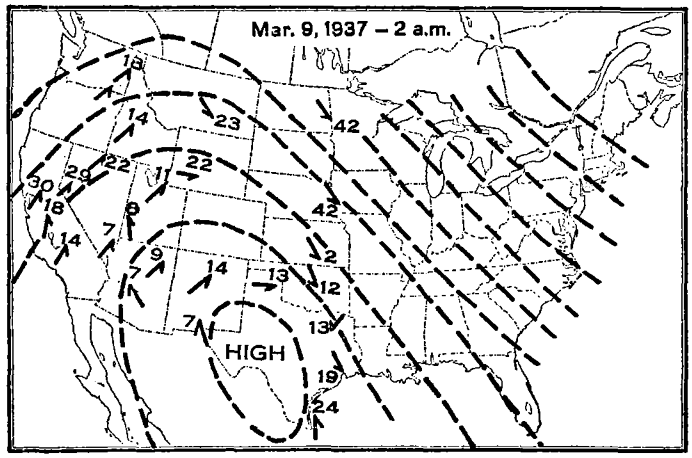

FIGURE 4.—Upper wind map for the 8,000-feet level, 2 a. m. Pacific standard time, March 9, 1937.

future. Fronts or wind shift lines are noted. They are frequently extensions of surface fronts and can be plotted accurately from consideration of the surface chart. Considerable attention should be given to noting changes of gradients in the moving systems to determine the areas of increasing or decreasing wind velocities. Since the wind direction is that of the tangent to the streamline changes in direction may easily be anticipated. With a small amount of practice the meteorologist will be able to visualize upper wind changes and give wind forecasts which are based on a thorough knowledge of the synoptic situation.

Such a series of maps not only enables the meteorologist to forecast accurately the wind distribution at any desired time but also to fill in missing wind reports. Occasionally large areas become overcast with low cloud systems and no observations can be made for long periods of time. If the streamline systems are carefully carried along from day to day even with only a few scattered reports, it is possible to give intelligent estimates of upper wind conditions for periods of from 24 to 48 hours.

Upper wind forecasts, which have been made for regular air line operation using these methods, have shown an extremely high degree of accuracy with only a few cases with deviations of more than 1 point in direction on an 8-point compass and 5 miles per hour in velocity.

At present only a few Weather Bureau stations use streamlines on the upper wind maps. The streamlines as used are only indications of direction and give no estimate of velocity.

From the standpoint of air line operation in the future with airplanes built to fly through heavy weather, operation will depend only upon two things, terminal conditions and the upper wind distribution.

It is hoped that by using a wind scale such as here described, upper wind forecasting will be put on more of a uniform basis.

CONCLUSIONS

1. Upper wind charts using streamlines which are tangent to the wind arrows and spaced according to the velocity give a clearer picture of the wind conditions aloft than charts using only wind arrows.

2. The isobars on the present weather map are used because they indicate the direction and velocity of the wind. Unless the meteorologist considers the change in pressure for rapidly moving pressure systems the winds computed from the isobars give only the conditions for a stationary system.

If instead of trying to deduce the wind velocities from something more or less intangible, wind direction and velocity are used directly, fewer errors are apt to arise.

3. A geostrophic wind scale may be laid out to aid in the construction of an upper-air streamline map.

AIR MASSES OF SOUTHERN BRAZIL

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[Departmento de Aeronáutica Civil, Rio de Janeiro, Brazil, October 1937]

From preliminary studies made on the atmospheric circulation of South America, the principal air masses that pass over Rio de Janeiro and Alegrete have been found to be the following:

Polar maritime (PM)—Polar maritime air masses originate in the region of the belt of low pressures or "brave west winds" of the Antarctic circle. They appear south of Brazil as anticyclones, which upon coming in contact with the tropical air masses form cold fronts along which storms develop.

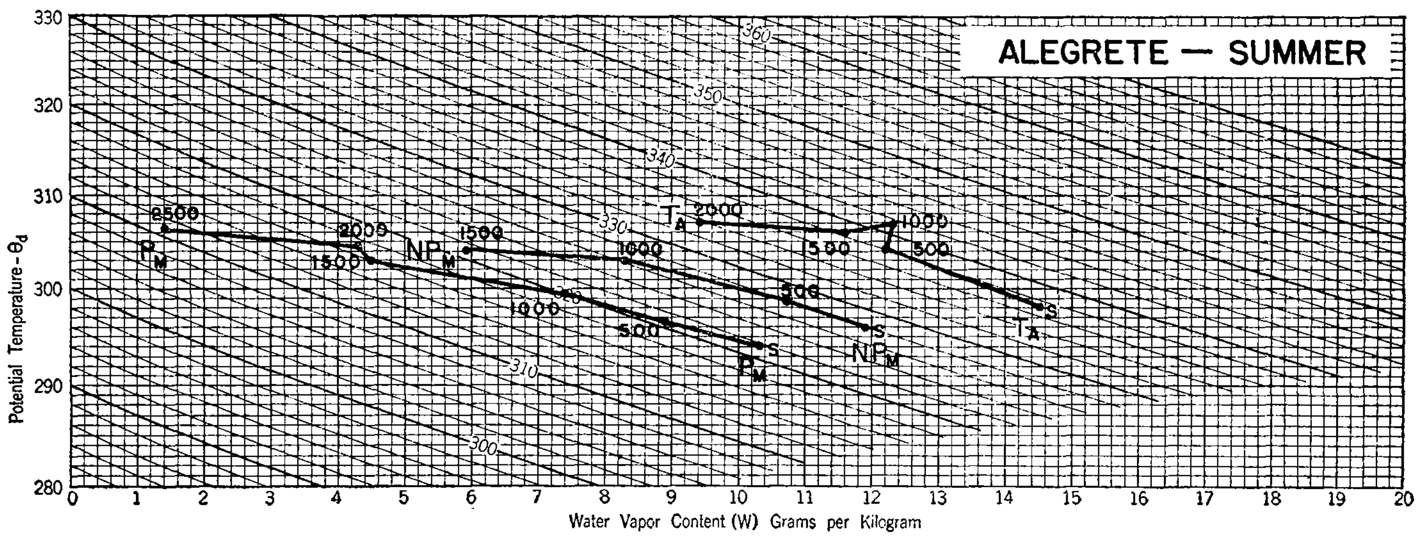

FIGURE 1.—Characteristic curves of air masses at Alegrete during summer.

In winter, in Alegrete, these masses are convectively unstable. They have low values of temperature and relative humidity because they are moving over regions which are warm relative to the source. These air masses frequently reach Rio de Janeiro but due to the accompanying bad weather, soundings are not practicable.

In summer, despite an increase in values of w and θ_E, the winter characteristics persist at Alegrete. In Rio de Janeiro, however, the relative humidity is at a maximum, as a result of abundant rainfall at cold front passages; the other characteristics remain unchanged.

The pronounced increase in the characteristic values at Rio de Janeiro over those observed at Alegrete should be noted. In general, stratification is not very marked, but rather a tendency to homogeneity is evident.

Modified polar maritime (NPM)—In proceeding to lower latitudes, the polar air decreases in velocity, and a modification takes place which is characterized by subsidence, decrease in cloudiness, and a gradual fusion with the tropical Atlantic air.

This modification is manifest in winter in Alegrete through the increase in characteristic values, greater stability at low levels, more pronounced stratification, surface temperature inversions, and decrease in relative humidity.

In summer the ordinarily high instability of the season at Alegrete hinders subsidence. In Rio de Janeiro, however, there is little difference between PM and NPM, although the latter air masses do have lower relative humidity values.

Tropical Atlantic (TA)—Tropical Atlantic air masses originate in the center of action of the south Atlantic and are transported by NE, N, and NW winds.

In winter these masses prevail at Rio de Janeiro (situated near the source region), almost exclusively. They show great instability at the surface, due to local heating, and small lapse rates. On account of their maritime origin they have high relative humidities.

These masses reach Alegrete after a long trajectory, and a gradual cooling can be noticed in the lower levels with a consequent increase in stability indicated by a surface inversion. Relative humidity remains high as a result of the lower temperature.

In summer, in Rio de Janeiro, stratification and instability are both pronounced, but the relative humidity, although high throughout the lower levels, decreases with